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CARDIAC RHYTHM MANAGEMENT SYSTEM WITH ARRHYTHMIA CLASSIFICATION AND ELECTRODE SELECTION SYSTEM

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CARDIAC RHYTHM MANAGEMENT SYSTEM WITH ARRHYTHMIA CLASSIFICATION AND ELECTRODE SELECTION

TECHNICAL FIELD

5   This document relates generally to cardiac rhythm management systems, devices, and/or methods, and particularly, but not by way of limitation, to a cardiac rhythm management system, device, and/or method that classifies an arrhythmia and selects electrodes for delivering antiarrhythmia therapy using the classification.

BACKGROUND

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When functioning properly, the human heart maintains its own intrinsic rhythm. Its sinoatrial node generates intrinsic electrical cardiac signals that depolarize the atria, causing atrial heart contractions. Its atrioventricular node then passes the intrinsic cardiac signal to depolarize the ventricles, causing ventricular

15   heart contractions. These intrinsic cardiac signals can be sensed on a surface electrocardiogram (ECG) obtained from electrodes placed on the patient's skin, or from electrodes implanted within the patient's body. The surface ECG waveform, for example, includes artifacts associated with atrial depolarizations ("P-waves") and those associated with ventricular depolarizations ("QRS complexes").

20   A normal heart is capable of pumping adequate blood throughout the body's circulatory system. However, some people have irregular cardiac rhythms, referred to as cardiac arrhythmias. Moreover, some patients have poorly spatially-coordinated heart contractions. In either case, diminished blood circulation may result. For such patients, a cardiac rhythm management system may be used to

25   improve the rhythm and/or spatial coordination of heart contractions. Such systems are often implanted in the patient and deliver therapy to the heart.

Cardiac rhythm management systems include, among other things, pacemakers, also referred to as pacers. Pacers deliver timed sequences of low energy electrical stimuli, called pace pulses, to the heart, such as via an intravascular

30   leadwire or catheter (referred to as a "lead") having one or more electrodes disposed

in or about the heart. Heart contractions are initiated in response to such pace pulses (this is referred to as "capturing" the heart). By properly timing the delivery of pace pulses, the heart can be induced to contract in proper rhythm, greatly improving its efficiency as a pump. Pacers are often used to treat patients with bradyarrhythmias,

5 that is, hearts that beat too slowly, or irregularly. Such pacers may also coordinate atrial and ventricular contractions to improve pumping efficiency. Cardiac rhythm management systems also include cardiac resynchronization therapy (CRT) devices for coordinating the spatial nature of heart depolarizations for improving pumping efficiency. For example, a CRT device may deliver appropriately timed pace pulses

10 to different locations of the same heart chamber to better coordinate the contraction of that heart chamber, or the CRT device may deliver appropriately timed pace pulses to different heart chambers to improve the manner in which these different heart chambers contract together.

Cardiac rhythm management systems also include defibrillators that are

15 capable of delivering higher energy electrical stimuli to the heart. Such defibrillators include cardioverters, which synchronize the delivery of such stimuli to portions of sensed intrinsic heart activity signals. Defibrillators are often used to treat patients with tachyarrhythmias, that is, hearts that beat too quickly. Such too-fast heart rhythms also cause diminished blood circulation because the heart isn't

20 allowed sufficient time to fill with blood before contracting to expel the blood. Such pumping by the heart is inefficient. A defibrillator is capable of delivering a high energy electrical stimulus that is sometimes referred to as a defibrillation countershock, also referred to simply as a "shock." The countershock interrupts the tachyarrhythmia, allowing the heart to reestablish a normal rhythm for the efficient

25 pumping of blood. In addition to pacers, CRT devices, and defibrillators, cardiac rhythm management systems also include devices that combine these functions, as well as monitors, drug delivery devices, and any other implantable or external systems or devices for diagnosing or treating the heart.

One problem faced by cardiac rhythm management devices is in determining

what type of antitachyarrhythmia therapy to deliver to a patient to interrupt a tachyarrhythmia. For example, antitachyarrhythmia pacing therapy (ATP) is typically preferred to delivering a countershock, since ATP is less painful to the patient. However, in some circumstances, ATP may also be less effective than

5   delivering a shock. Also, the present inventors have recognized that where a plurality of electrodes are associated with the region of the heart to receive antitachyarrhythmia treatment, delivering antitachyarrhythmia therapy from certain electrode(s) may be more effective than delivering the therapy from other electrode(s). The present inventors have also recognized that the efficacy of a

10   particular therapy regimen and/or the selection of particular electrode(s) to provide the therapy may depend on the nature of the arrhythmia itself. For these reasons, the present inventors have recognized a need for classifying an arrhythmia and using the classification to guide the choice and/or nature of the antitachyarrhythmia therapy and/or its delivery.

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SUMMARY

This document discusses, among other things, a system, method, or device that classifies an arrhythmia according to the temporal order in which a depolarization wave associated with a particular heart contraction is received at a

20   plurality of electrodes. One or more antiarrhythmia therapies is mapped to each arrhythmia classification. When a particularly classified arrhythmia is detected, the correspondingly mapped therapy list is selected and an appropriate antiarrhythmia therapy delivered. In one example, the particular therapy delivered in response to an arrhythmia depends at least in part on its historical success in treating arrhythmias of

25   that classification.

In one example, this document discusses a cardiac rhythm management system. The cardiac rhythm management system includes a plurality of electrodes associated with a heart. A cardiac signal detector circuit is coupled to the electrodes. An energy output circuit is also coupled to at least one of the electrodes.

A controller is coupled to the cardiac signal detector and the energy output circuit. The controller includes an arrhythmia detector module. The controller also includes an arrhythmia classifier module, to classify the detected arrhythmia according to a sequence in which a heart contraction depolarization is received at the electrodes.

5   The controller further includes a therapy map, providing an antiarrhythmia therapy corresponding to the arrhythmia classification. The controller issues a control signal to the energy output circuit to deliver a selected antiarrhythmia therapy corresponding to an arrhythmia classification.

In another example, this document also discusses a method. The method

10   includes detecting an arrhythmia at a plurality of electrodes, classifying the detected arrhythmia according to a sequence in which a heart contraction depolarization is received at the electrodes, selecting an antiarrhythmia therapy corresponding to the arrhythmia classification, and delivering the selected antiarrhythmia therapy by issuing a control signal to the energy output circuit. Other aspects of the invention

15   will be apparent on reading the following detailed description of the invention and viewing the drawings that form a part thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which are offered by way of example, and not by way of

20   limitation, and which are not necessarily drawn to scale, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components.

Figure 1 is a block diagram illustrating generally portions of a cardiac

25   rhythm management system and portions of an environment in which it is used.

Figure 2 is a schematic illustration of an example electrode configuration for one example classifying an arrhythmia and selecting appropriate electrode(s) and/or a therapy regimen to be delivered from the selected electrode(s).

Figure 3 is a flow chart illustrating generally an overview of one example of

a method for classifying and treating an arrhythmia.

Figure 4 is a flow chart illustrating generally another example of a method for classifying and treating an arrhythmia.

Figure 5 is a flow chart illustrating generally another example of a method for classifying and treating an arrhythmia.

Figure 6 is a flow chart illustrating an example of classifying an arrhythmia and escalating to an appropriately-ranked therapy, such using a number of times an arrhythmia has been redetected during a particular arrhythmia episode.

Figure 7 is a timing diagram for two electrodes, in which an interelectrode delay is decreased to maintain a substantially constant coupling interval.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that the embodiments may be combined, or that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

Figure 1 is a block diagram illustrating generally portions of a cardiac rhythm management system 100 and portions of an environment in which it is used. In this example, system 100 includes a cardiac rhythm management device 102 coupled to a heart 104 by one or more electrodes associated with heart 104, such as for sensing intrinsic cardiac signals and/or for delivering energy or other therapy to heart 104. System 100 may also include a programmer or other remote interface 106, which is wirelessly or otherwise communicatively coupled to a telemetry

circuit **108** or other communication circuit in device **102**. Device **102** includes a pacer, a defibrillator, a cardiac resynchronization therapy (CRT) device, a monitor, a device that combines more than one of these functions, or any other implantable or external device for diagnosing and/or treating the heart.

5   In one example, device **102** is sized and shaped for being pectorally or abdominally implanted in a human patient. The electrode(s) coupling device **102** to heart **104** may include an intravascular electrode, an intracardiac electrode, an epicardial electrode, or a housing or a header electrode located on a housing of device **102** or a header attached thereto, or any combination of the above. In some

10   configurations, such as where portion(s) of device **102** are external to the patient, the electrode(s) coupling device **102** to heart **104** may include a skin surface electrode external to the patient. The electrodes may be associated with the heart for bipolar (i.e., two electrodes that are relatively close together) or for unipolar (i.e., two electrodes that are farther apart) signal sensing or therapy energy delivery (e.g.,

15   pacing pulse or shocks).

        In the example of Figure 1, device **102** includes a cardiac signal detector **110** having an input coupled to heart **104** by electrodes associated with heart **104** in a suitable manner for sensing an intrinsic cardiac signal. Detector **110** typically includes a sense amplifier for acquiring and amplifying the cardiac signal. Detector

20   **110** may also include one or more continuous-time and/or discrete time (e.g., switched-capacitor) filter circuits, such as for selectively emphasizing the desired heart depolarization information relative to other acquired signal content. Detector **110** may also include an analog-to-digital converter (ADC) to convert continuous-time and/or discrete time samples into numerical representations of those samples.

25   Detector **110** may also include one or more digital filters (or other digital signal processing circuitry) following the ADC, such as for selectively emphasizing the desired heart depolarization information relative to other acquired signal content.

        Detector **110** also extracts heart depolarizations (or another feature corresponding to a heart contraction) from the sensed intrinsic cardiac signal

associated with each electrode, together with the corresponding time of occurrence of the depolarization. In one example, detector **110** detects depolarizations using a level detector circuit. Detector **110** outputs an indication of the occurrence (and time) of the depolarization to controller **114** circuit for further processing.

5   Controller **114** is capable of sequencing through various control states such as, for example, by using a digital microprocessor having executable instructions stored in an associated instruction memory circuit, a microsequencer, or a state machine. In operation, by executing these instructions, controller **114** provides control signals to cardiac signal detector **110** and an energy output circuit **118**. In this example,

10   controller **114** includes an arrhythmia detector module **122**, for detecting an arrhythmia based on the depolarization information from cardiac signal detector **110** (e.g., detecting depolarizations above a critical rate may indicate a tachyarrhythmia). Controller **114** also includes an arrhythmia classifier **124**, for classifying the detected arrhythmia, such as according to a sequence in which a heart contraction

15   depolarization is received at various electrodes. Controller **114** also includes a therapy map **126** stored in memory, mapping a predetermined therapy (or list of therapies) to each arrhthmia classification. Among other things, the control signals from controller **114** to energy output circuit **118** direct the appropriate delivery of antitachyarrhythmia therapy based on the nature of the arrhythmia as sensed from

20   the electrodes by cardiac signal detector **110** and as classified by controller **114**. Energy output circuit **118** is coupled to one or more electrodes associated with the heart **104**. Energy output circuit **118** provides pacing or resynchronization pulses, defibrillation shocks, or other appropriate cardiac therapy to heart **104**. Device **102** also includes a battery or other power source **120**.

25   Figure **2** is a schematic illustration of an example electrode configuration for use with one example of the present technique for classifying an arrhythmia and selecting appropriate electrode(s) and/or a therapy regimen to be delivered from the selected electrode(s). In this example, device **102** is associated with heart **104** using an intravascular right ventricular (RV1) electrode **200**, which is disposed at or

near the apex of the right ventricle of heart **104**. First and second left ventricular

(LV1, LV2) electrodes **205** and **210**, respectively, are introduced through a coronary

sinus into the great cardiac vein into association with the left ventricle of heart **104**.

In this example, LV1 electrode **205** is located near a basal portion of the left

5 ventricle, and LV2 electrode **210** is located near a more apical portion of the left

ventricle. Figure **2** is merely an illustrative example of one possible electrode

configuration for use with the present system and methods, other suitable electrode

configurations may include fewer electrodes or more electrodes, and may be

disposed elsewhere in association with heart **104**.

10 Figure **3** is a flow chart illustrating generally an overview of one example of

a method carried out by device **102** (e.g., by executing a sequence of instructions

using controller **114**) for classifying and treating an arrhythmia. At **300**, an

arrhythmia is detected. For example, the arrhythmia may be detected by detecting a

rate of heart depolarizations associated with a particular chamber, and comparing

15 the rate to one or more threshold values. For example, a detected depolarization rate

exceeding a critical rate threshold value may be deemed a tachyarrhythmia. At **305**,

the arrhythmia is classified, for example, by noting the temporal order in which a

depolarization associated with a particular heart contraction was received at multiple

electrodes (e.g., RV then LV1 then LV2, or LV1 then RV then LV2, etc.). At **310**, a

20 therapy is delivered based upon the classification such as, for example, by mapping

a particular therapy to each arrhythmia classification. In a further example, the

particular therapy that is delivered may depend on whether that therapy was

previously successful at treating that arrhythmia.

25 Table **1**: Example of Arrhythmia Classification and Therapy Selection.

Detection Sequence	Arrhythmia Classification	Therapy
(RV1, LV1, LV2)	AR1	TH1
(RV1, LV2, LV1)	AR2	TH2

(LV1, RV1, LV2)	AR3	TH3
(LV1, LV2, RV1)	AR4	TH4
(LV2, RV1, LV1)	AR5	TH5
(LV2, LV1, RV1)	AR6	TH6

5

Table 1 illustrates one possible arrhythmia classification scheme, with each classified arrhythmia mapped to at least one therapy. As discussed below, however, each therapy TH1, TH2, etc. may represent a single antiarrhythmia therapy, or may instead represent a ranked or other list of therapies, from which a particular therapy

10   is selected. In this example, the arrhythmia is classified based on the order in which a depolarization (or other feature) associated with a particular heart contraction is received at the various electrodes illustrated in Figure 2. For example, the sequence (RV1, LV1, LV2) represents an arrhythmia state for which a heart contraction is detected first at RV1 electrode **200**, then at LV1 electrode **205**, then at LV2

15   electrode **210**.

This classification may be performed with respect to a single heart contraction during the arrhythmia. Alternatively, the classification is repeatedly performed over a plurality of heart contractions during the arrhythmia. In that case, the most prevalent sequence (if any) is used to classify the arrhythmia. Moreover,

20   an indication of the prevalence and/or variability of the sequence may also be provided. In one example, such a prevalence indication is relevant to the "confidence" that the arrhythmia is properly classified. In another example, such a variability indication is relevant to whether the arrhythmia is stable or unstable. Therefore, this prevalence or variability indication may also be used as a factor for

25   determining which therapy to invoke. For example, TH1 may be an antitachyarrhythmia pacing (ATP) sequence issued from a particular electrode or set of electrodes in a particular way, but if the arrhythmia classification variability indicator indicates that the arrhythmia is unstable, the mapped therapy TH1 may be overridden and a more painful (but likely more effective) countershock issued

instead.

In a further example, the six arrhythmia classifications in Table **1** are expanded to 54 possible arrhythmia classifications by including information about the relative time difference with which the same heart contraction was detected at the different electrodes, and classifying that time difference, for example, into three possible states. By way of illustrative example, but not by way of limitation, a time difference that is less than or equal to 10 milliseconds is deemed small ("S"), a time difference that is between 10 milliseconds and 50 milliseconds is deemed medium ("M"), and a time difference that equals or exceeds 50 milliseconds is deemed large ("L"). Using these three categorizations of the timing relationships, each detection sequence entry in Table **1** can be expanded into nine timing sequence entries. An example of such an expansion of the first detection sequence entry in Table **1**, (RV1, LV1, LV2), is illustrated below in Table **2**.

Table 2. Example of expansion of (RV1, LV1, LV2) in Table **1**

Detection Sequence Timing	Arrhythmia Classification	Therapy
(RV1, S, LV1, S, LV2)	AR1	TH1
(RV1, S, LV1, M, LV2)	AR2	TH2
(RV1, M, LV1, S, LV2)	AR3	TH3
(RV1, M, LV1, M, LV2)	AR4	TH4
(RV1, S, LV1, L, LV2)	AR5	TH5
(RV1, L, LV1, S, LV2)	AR6	TH6
(RV1, L, LV1, L, LV2)	AR7	TH7
(RV1, M, LV1, L, LV2)	AR8	TH8
(RV1, L, LV1, M, LV2)	AR9	TH9

In Table **2**, for example, the third entry (RV1, M, LV1, S, LV2), represents a

heart contraction that is detected first at RV1 electrode 200, followed by a detection

of the same heart contraction at LV1 electrode 205 that occurs between 10 and 50

milliseconds after the detection at RV1 electrode 200, followed by a detection of the

same heart contraction at LV2 electrode 210 that occurs less than or equal to 10

5   milliseconds after the detection at LV1 electrode 205. This detection timing

sequence is mapped to a particular arrhythmia classification, AR3, which, in turn, is

mapped to at least one therapy, TH3. Tables similar to Table 2 can be created for

each of the entries in Table 1, yielding, in this example, 54 arrhythmia

classifications, each mapped to a corresponding therapy or therapies.

10   The arrhythmia classification techniques discussed in this document need not

be performed using only temporal sequence and timing differences. Other

physiological information can also be used perform the classification. For example,

the detected heart rate may be compared to one or more user-programmable

thresholds to determine a heart rate zone used to further classify the arrhythmia.

15   One suitable example providing three rate zones (referred to as "VT-1," "VT," and

"VF") for classifying arrhythmias is described in Krig et al. U.S. Patent No.

5,978,707, entitled APPARATUS AND METHOD FOR TREATING

VENTRICULAR ARRHYTHMIAS, which is assigned to Cardiac Pacemakers, Inc.,

and which is incorporated herein by reference in its entirety, including its disclosure

20   of classifying arrhythmias according to heart rate zones, and of providing

antiarrhythmia therapy based on the heart rate zone classification, and of providing

various ATP and other antiarrhythmia therapy schemes. One suitable example of

displaying such rate zone and other parameter information for the user is described

in Conley et al. U.S. Patent No. 6,289,248, entitled APPARATUS AND METHOD

25   FOR TREATING VENTRICULAR ARRHYTHMIAS, which is assigned to Cardiac

Pacemakers, Inc., and which is incorporated herein by reference in its entirety,

including its disclosure of displaying, on an external interface device, parameters for

classifying arrhythmias according to heart rate zones, and of displaying parameters

for providing antiarrhythmia therapy based on the heart rate zone classification. An

example of expanding the first detection sequence entry in Table **1**, (RV1, LV1,

LV2), to also use a heart rate zone arrhythmia classification, such as discussed in

Krig et al. U.S. Patent No. 5,978,707, is illustrated below in Table **3**.

5   Table **3**: Example of expansion of (RV1, LV1, LV2) in Table **1**.

Detection Sequence and Heart Rate Zone	Arrhythmia Classification	Therapy
(RV1, LV1, LV2, VT-1)	AR1	TH1
(RV1, LV1, LV2, VT)	AR2	TH2
(RV1, LV1, LV2, VF)	AR3	TH3

10

Figure **4** is a flow chart illustrating generally another example of a method

carried out by device **102** for classifying and treating an arrhythmia. At **400**, an

arrhythmia is detected, for example, by detecting a rate of heart depolarizations

15   associated with a particular chamber, and comparing the rate to one or more

threshold values (e.g., rate exceeding a critical rate threshold value may be deemed a

tachyarrhythmia). At **405**, the relative sequence in which a particular depolarization

or other indication of a particular heart contraction is received at the electrodes is

detected. This may further include computing and/or classifying the relative time

20   differences between the detections at the various electrodes. At **410**, the arrhythmia

is classified, for example, by noting the temporal order (i.e., relative sequence) in

which a depolarization associated with a particular heart contraction was received at

multiple electrodes (e.g., RV then LV1 then LV2, or LV1 then RV then LV2, etc.).

As illustrated in Table **2**, the classification may further use the time differences

25   between the receptions of the depolarization and the various electrodes. As

illustrated in Table **3**, the classification may further use a heart rate zone, or other

physiological information. At **415**, based on the arrhythmia classification, a therapy

is selected from a corresponding therapy list that is mapped to that arrhythmia

classification. While each therapy list may include a single therapy, in one example,

the therapy list includes a plurality of therapies, each therapy having a corresponding probability or other estimate of its successfulness in treating the classified arrhythmia. At **420**, a particular therapy from the therapy list corresponding to the arrhythmia classification is selected using the success estimates for the therapies on

5   the therapy list. For example, a therapy having an associated high success estimate (e.g., based on a previous successful treatment of the classified arrhythmia using the therapy), is more likely to be selected than a therapy having an associated lower success estimate. The success estimate may also factor in any undesirability of applying the therapy to the patient such as, for example, the pain experienced when

10   a defibrillation countershock is delivered to the patient. At **425**, the therapy is applied to the heart, such as via the electrodes associated with the heart. At **430**, a determination is made as to whether the application of the therapy succeeded at treating the arrhythmia. For example, a decrease in heart rate below a critical threshold value may indicate successful treatment of a tachyarrhythmia. If, at **430**,

15   the therapy was successful at treating the arrhythmia, then at **435**, the success estimate of the applied therapy is updated to reflect this success, and process flow returns to **400** to await detection of another arrhythmia. If, at **430**, the therapy was not successful at treating the arrhythmia, then at **440** the success estimate of the applied therapy is updated to reflect this failure, and process flow returns to **420** to

20   select another therapy from the therapy list associated with the classified arrhythmia.

In a further example, a predetermined number of failures at **430** triggers an escalated therapy (e.g., defibrillation shock) believed more effective at treating the arrhythmia, but which has been withheld because of other undesirable effects such as, for example, the pain experienced by a patient upon receiving a defibrillation

25   shock, and unnecessary battery depletion and shortened device longevity from delivering the shock.. An example of this technique is illustrated in the flow chart Figure **5**, which is slightly modified from that of Figure **4**. In Figure **5**, at **400**, upon detection of the arrhythmia, a counter is also reset. After therapy is applied at **425**, if the therapy was not successful in interrupting the tachyarrhythmia, as determined at

430 (e.g., by redetecting whether an arrhythmia is still present), then the success estimate is updated at **440**, and the counter is incremented. Then, at **500** if the counter exceeds a predetermined threshold (e.g., three failures), therapy is escalated by delivering a shock at **505**. Process flow returns to **430** to determine whether the delivered shock was successful. If, at **500**, the counter does not exceed the predetermined threshold, another therapy is selected from the therapy list corresponding to the classified tachyarrhythmia.

In Figures **4** and **5**, an unsuccessful application of antiarrhythmia therapy at **425** may, however, effectively change the nature of the arrhythmia such that it would be differently classified at **410** and, therefore, perhaps differently treated. Accordingly, in an alternative method of operation, process flow from **440** and **500** returns to **405**, rather than to **420**, as illustrated by the extended dashed lines in Figures **4** and **5**. Similarly, process flow from **505** returns to **400**, rather than to **430**, as illustrated by the extended dashed line in Figure **5**. Such techniques allows the arrhythmia to be reclassified at **410** to determine whether the previously-applied therapy effectively changed the earlier arrhythmia classification.

In Figures **4** and **5**, the success estimate may initially be seeded (e.g., at the factory or via programming by a physician or other user) to reflect an initial estimate of how successful a particular therapy in the therapy list will be at treating the particularly classified arrhythmia. If the user has no inclinations toward a particular therapy, for example, each therapy on the list could be seeded with a 50% success estimate, with the success estimate updated according to the number of successes for that therapy divided by the total number of trials of that therapy. Otherwise, Figures **4** and **5** reflect a continuous looping process, such that the illustrated acts are invoked whenever an arrhythmia is detected at **400** in a patient.

Figure **6** is a flow chart illustrating an alternate example of classifying an arrhythmia and escalating to an appropriately-ranked therapy within a list corresponding to the arrhythmia classification, such as based on a number of times an arrhythmia has been redetected during a particular arrhythmia episode. At **600**,

an arrhythmia is detected, such as using the techniques discussed above. By comparing a timer value (which was started upon a previous arrhythmia detection) to a predetermined threshold value, the arrhythmia is deemed to be a redetected occurrence of the same arrhythmic episode if the timer value is less than the

5 predetermined comparison value. At **405**, depolarization receptions are detected at electrodes, such as using the techniques discussed above. At **410**, the arrhythmia is classified using a depolarization reception sequence and/or relative depolarization reception times, together with any other suitable criteria for classifying an arrhythmia (e.g., heart rate within a particular heart rate zone, as discussed above).

10 At **415**, a therapy list, corresponding to the arrhythmia classification, is selected. The therapy list includes a predetermined number (e.g., five) of ranked therapies, some or all of which may be user-programmable. At **605**, a particular therapy in the selected therapy list is selected based on the number of times the arrhythmia has been redetected during the same arrhythmic episode (however, the arrhythmia may

15 alternatively represent a new arrhythmic episode). For example, a newly detected arrhythmia episode may be given an index of "0" within the therapy list. This would correspond to a less severe therapy than an arrhythmia that has been redetected twice, which may be given an index of "2" within the therapy list, corresponding to a more severe therapy. At **425** the selected therapy is delivered, as discussed above.

20 In one implementation of this technique, the arrhythmia may be reclassified during the same arrhythmic episode, but the ranking in the new therapy list is based on a number of arrhythmia redetections after therapy is applied from any of the therapy lists. In another implementation of this technique, if the arrhythmia is reclassified during the same arrhythmic episode, the ranking in the new therapy list is based on a

25 number of arrhythmia redetections after therapy was applied from that particular new therapy list.

In the example of Figure **6**, if the arrhythmic episode should persist even after the highest-ranked (most severe) therapy is delivered, in one example, antiarrhythmia therapy is subsequently inhibited during the remainder of that

arrhythmia episode. In another example, such a persistent arrhythmic episode continues to trigger therapy delivery. In a further example, whether such a persistent arrhythmic episode continues to deliver therapy depends at least in part on the arrhythmia classification.

5   In Tables 1 and 2 above, each therapy TH1, TH2, etc. may represent a single therapy that is mapped to the corresponding arrhythmia, or instead, each may represent a plurality of ranked or unranked therapies, each of which is mapped to the corresponding arrhythmia. For example, TH1 may include several possible antitachyarrhythmia pacing (ATP) therapies, several possible cardioversion therapies, and several possible shock therapies. An ATP therapy typically provides one or more pacing pulses timed to interrupt a reentrant loop heart depolarization (e.g., due to scar tissue) causing the tachyarrhythmia. This can be accomplished with a single pulse or a series of pulses, one of which is timed correctly to enter the reentrant loop termination zone. ATP therapy may involve several parameters; different combinations of parameter settings may be regarded as distinct therapies on the therapy list TH1, TH2, etc. Such ATP parameters may include, among other things, number of pulses, timing of the first pulse with respect to an immediately preceding sensed ventricular depolarization (referred to as a coupling interval), timing between ATP pulses (each ATP pulse corresponding to a particular heart contraction) in an ATP sequence of ATP pulses, and interelectrode timing for a particular ATP pulse. Other ATP parameters control various schemes for overdriving the intrinsic heart rate with an ATP sequence, then ramping down the ATP pulse delivery rate, suddenly lowering the ATP pulse delivery rate, or stopping abruptly the delivery of ATP pulses altogether at the end of the ATP sequence. One example of delivering one or more ATP pulses is discussed in Spinelli et al. U.S. Patent Application Serial No. _____ (bearing attorney docket number 279.375US1), entitled "APPARATUS AND METHOD FOR MULTI-SITE ANTI-TACHYCARDIA PACING," filed on even date and assigned to Cardiac Pacemakers, Inc., which is incorporated herein by reference in its entirety.

A particular therapy may differ from other therapies by, among other things, being delivered from one or more different electrodes. For example, for the electrode configuration illustrated in Figure 2, ATP can be delivered from the following electrode(s): (RV), (LV1), (LV2), (RV, LV1), (RV, LV2), (LV1, LV2),

5   (RV, LV1, LV2). Each such electrode combination may represent a distinct therapy on a list of therapies such as TH1.

Moreover, where an ATP pulse or sequence of pulses is delivered from more than one electrode, the ATP pulses can be delivered simultaneously from the electrodes, or may incorporate a slight temporal offset from the delivery of a

10   corresponding pulse to one or more other electrodes. For example, for the electrode configuration illustrated in Figure 2, ATP can be delivered using the following electrode sequences: (RV), (LV1), (LV2), (RV, LV1), (LV1, RV), (RV, LV2), (LV2, RV), (LV1, LV2), (LV2, LV1), (RV, LV1, LV2), (RV, LV2, LV1), (LV1, RV, LV2), (LV1, RV, LV2), (LV1, LV2, RV), (LV2, RV, LV1), (LV2, LV1, RV).

15   Each such electrode sequence may constitute a distinct therapy on a list of therapies such as TH1.

Moreover, an ATP pulse sequence can trigger a particular heart contraction by issuing these pulses either simultaneously, or using predetermined temporal offset value(s) to resynchronize or otherwise better coordinate the spatial nature of

20   the heart depolarization wave associated with the heart contraction. Therefore, each of the above therapies can be further expanded into a list of therapies that incorporates such temporal offset information. In one example, this relative interelectrode timing is classified as follows: "S," indicating simultaneous pulse issuance at two electrodes, "SM" indicating that a pulse is delivered from the second

25   electrode in the sequence at a small (e.g., less than or equal to 10 millisecond) predetermined delay from the first electrode in the sequence, "M" indicating that the pulse is delivered from the second electrode in the sequence at a medium (e.g., between 10 and 20 millisecond) predetermined delay from the first electrode in the sequence, and "H," indicating that the pulse is delivered from the second electrode

in the sequence at a high (e.g., greater than or equal to 20 millisecond) predetermined delay from the first electrode in the sequence. For an illustrative example, the sequence.(RV, LV1) above can be thus expanded as the following therapies: (RV, S, LV1), (RV, SM, LV1), (RV, M, LV1), and (RV, H, LV1). The therapy list corresponding to a particular arrhythmia, however, need not include the complete expanded list of therapies. A predetermined subset of available therapies may be factory-set or programmably selected by a physician or other user, as being mapped to a particular arrhythmia.

Among other things, the present inventors have recognized that the detection sequence and/or detection sequence timing of a particular arrhythmia may suggest or even determine the most appropriate sequence in which ATP pulses should be delivered to treat that particular arrhythmia. For an illustrative example, a (RV1, M, LV1, M, LV2) arrhythmia detection sequence may suggest delivering an ATP therapy using a (RV, M, LV1, M, LV2) temporal offset arrangement for an ATP pulse in an ATP pulse sequence. In another example, a (RV1, S, LV1, M, LV2) arrhythmia detection sequence may suggest delivering an ATP therapy using a (RV1, S, LV1, M, LV2) temporal offset arrangement for an ATP pulse in a ATP pulse sequence.

The interelectrode temporal offset intervals for a particular ATP pace pulse need not be fixed. In one example, a sequence of ATP pace pulses is delivered at a constant coupling interval while sequentially ramping down (decreasing) the interelectrode delay. One example of such an ATP therapy is illustrated in the timing diagram of Figure 7, which uses a two electrode configuration (e.g., RV and LV2 of Figure 2) as an illustrative example. In Figure 7, trace **700** represents timing of signals occurring at RV electrode **200**. Trace **705** represents timing of signals occurring at LV2 electrode **210**. At **710**, a ventricular depolarization is sensed at RV electrode **200**, triggering delivery of an ATP pace pulse at **720**. At **715**, the same ventricular depolarization is sensed at LV2 electrode **210**, triggering delivery of an ATP pace pulse at **725**. In this illustration, the coupling interval is defined as

the time between the earliest sense of a particular ventricular depolarization at one of the electrodes associated with the ventricles and the immediately succeeding delivery of an ATP pulse at that same electrode. In Figure 7, for example, the coupling interval is the time between **720** and **710**. In one example, the

5 interelectrode delay between delivering ATP pulses (e.g., the time between **725** and **720**) is incrementally or otherwise decreased during successive ATP pulses in the ATP sequence. For example, in Figure 7, where the coupling interval is 300 milliseconds, and the interelectrode sensing delay (e.g., the time between **715** and **710**) is 150 milliseconds, the first ATP pulse in the ATP pulse sequence is delivered

10 from each electrode at 300 milliseconds after its respective sense. Then, the interelectrode pacing delay is incrementally decreased to 100 milliseconds, then 50 milliseconds, then 0 milliseconds on subsequent ATP pulses, as illustrated in Figure 7. Thus, Figure 7 illustrates one example of a particular ATP therapy sequence constituting one therapy on a list of therapies mapped to a particular classified

15 arrhythmia.

In addition to the distinct ATP therapies discussed above, a cardioversion or defibrillation shock therapy may also be expanded into a plurality of possible therapies that may be included on a particular therapy list such as TH1. For example, a defibrillation shock may be provided using several different energy

20 levels and/or waveforms each of which may constitute a distinct therapy on a particular therapy list such as TH1. Examples of variations in antitachyarrhythmia therapy, including discrete ATP therapies and discrete defibrillation shock therapies, are discussed in Krig et al. U.S. Patent No. 6,151,524, entitled "APPARATUS AND METHOD FOR TREATING VENTRICULAR TACHYARRHYTHMIAS," which

25 is assigned to Cardiac Pacemakers, Inc., and which is incorporated herein by reference in its entirety. This patent also describes techniques for escalating to a second therapy if a first therapy fails to interrupt the tachyarrhythmia.

<u>Conclusion</u>

It is to be understood that the above description is intended to be illustrative,

and not restrictive. For example, the above-discussed embodiments may be used in combination with each other. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein."